Design Report for a Fish Passage Improvement Project on Woodacre Creek at Carson Road

April 20, 2007

Prepared for:
Stetson Engineering
and
Marin County Department of Public Works

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Project Description

Michael Love & Associates has been contracted through Stetson Engineers to develop a conceptual fish passage design for Woodacre Creek at Carson Road for the County of Marin. The existing crossing is located approximately 80 feet downstream of the confluence of the West and East Forks of Woodacre Creeks and about 3,000 feet upstream of the recently replaced Park Street crossing on Woodacre Creek.

The existing crossing consists of two 55 foot long circular culverts; a 4 foot diameter corrugated steel pipe (CSP) with a 1.8% slope, and a 5 foot diameter smooth concrete pipe with a 0.9% slope. The invert in the CSP has rusted-through, allowing water to flow through the fill. Together, the culverts are estimated to convey only the 10-year peak flow before becoming overtopped (Taylor 2003).

The County requested a design be developed for improving upstream fish passage conditions with a replacement crossing structure. The design must accommodate both upstream and downstream passage for adult and juvenile coho salmon and steelhead trout and convey the 100-year peak flow and associate debris.

The concept design presented in this report has been provided to Stetson Engineers for incorporation into the overall project design and engineering. Additionally, Michael Love & Associates reviewed and commented on each submittal of the draft plans developed by Stetson to ensure they are consistent with the overall concept design.

Existing Fish Passage Conditions

The existing two culverts on Carson Road were identified in the County fish passage assessment (Taylor, 2003) as being a partial barrier to adult salmon and steelhead and a complete barrier juvenile salmonids.

The crossing, referred to as Woodacre #3 in the County assessment report, was ranked 14th in priority for treatment. The report recommends increasing this crossing's rank to include it in a comprehensive plan for improving fish passage and ecological continuity throughout Woodacre Creek.

Preferred Design Approach

Woodacre Creek downstream of the crossing is characterized as a confined channel with numerous hard bedrock outcrops that control the channel grade. A large bedrock outcropping spans the channel below the culvert outlet, forming the tailwater control for the outlet pool and prevented the culvert outlet from becoming perched (**Figure 1**).

Figure 1 – Outlet of the two culverts on Woodacre Creek at Carson Road. Note the hard bedrock spanning the channel and forming the tailwater control for the outlet scour pool.

The project site appears suited for a *stream simulation* design approach, as indicated by the longitudinal profile of the channel through the culverts. The profile extends 300 feet downstream and 600 feet upstream of the Carson Road crossing. Throughout the profile the channel slope averages 2%, with little variation, and there appears to be no difference in grade between the upstream and downstream channel reaches. The hard bedrock controls in the downstream channel suggest the grade in this reach will remain stable.

The preferred alternative for the site is to replace the two existing crossings with a large span, low profile, bottomless culvert and create a naturalized channel with a substrate, slope, and width characteristic of the adjacent stream channel. Because of the presence of shallow bedrock, embedding a closed-bottom culvert was deemed impractical.

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Stream Simulation Design

Stetson Engineers conducted a topographic survey of the road, culvert, and adjacent channel and flood prone terraces. The survey also captured the location of structures in and adjacent to the channel. This survey was used to develop the conceptual fish passage design for the crossing.

Stream Simulation Design Criteria

The CDFG and NOAA Fisheries fish passage guidelines prescribe the following stream simulation design criteria for crossings:

- Culvert width shall be equal to or greater than the bankfull width.

- Culvert slope shall approximate the slope of the streambed through the reach in which it is being placed.

- Streambed material within the culvert shall address stability at high flows and be similar to the adjacent channel.

Design Objectives and Constraints

The objective of a stream simulation design is to provide passage for all native fish and other aquatic fauna through the Woodacre Creek crossing on Carson Road by constructing a natural streambed resembling the geomorphic conditions within the adjacent channel. This type of road-stream crossing maintains ecological connectivity by allowing free passage of water, aquatic organisms, streambed material, and woody debris.

Site constraints include the low profile of the road and poor alignment between the upstream channel and the culvert inlet. The roadbed is only 8 feet above the channel bed at the culvert inlet, requiring a low-profile type culvert be installed to obtain the required width-height dimensions. Changing the alignment of the culvert was evaluated but considered not feasible, although small changes to the channel alignment to improve the approach are possible.

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Additional constraint exists concerning the numerous structures in and adjacent to the upstream channel. They include:

1. A stone-masonry retaining wall defining the right bank above the culvert inlet.

2. The corner of a house located only 4 feet from the right edge of the channel near the culvert inlet.

3. A deck spanning the channel 45 feet upstream of the culvert inlet, which is supported by a log crib wall in the active channel

4. The East Fork of the creek, 120 feet upstream of the culvert inlet, flows across an at-grade concrete apron under a house.

Protecting these upstream structures by maintaining the existing upstream channel grade at the site is essential, and field evidence suggests that the upstream channel bed has slightly aggraded due to the hydraulic constriction created by the existing culverts.

Design Flows

Development of the conceptual design required estimating the structural design flow for the new crossing and channel bed. The following watershed statistics were estimated to develop design flows:

Contributing Drainage Area = 1.1 mi^2
Mean Annual Precipitation = 44 inches/year (from USDA-NRCS, 1999)

Structural Design Flows

The structural design flow for maintaining a new channel bed and sizing for the new crossing was the peak flow having a 100-year return period (Q_{100}). The peak flow associated with the 2-year (Q_2) and 1.5-year ($Q_{1.5}$) return periods were estimated to assist in determining appropriate "bankfull" channel geometry. The $Q_{100,}$ Q_2, and $Q_{1.5}$ were provided in the Hydrology Report, Marin County culvert enhancement projects (Stetson Engineers 2006) and estimated to be 340 cfs, 112 cfs, and 60 cfs, respectively.

Design Slope

The stable design slope and vertical adjustment potential (amount streambed may reasonably be expected to aggrade/degrade) for the new crossing was estimated using the longitudinal profile and based on locations and elevations of grade controlling features, including downstream bedrock and upstream culverts) (**Figure 2**). The channel bed below existing outlet scour pool is completely controlled by bedrock, serving as a downstream stable point. Upstream 275 feet is the tailwater control for the scour pool

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formed by the culvert under Garden Way. In the project reach the average channel slope is 1.9%. **Based on the channel profile, the design slope for streambed through the new crossing is 2.0%.**
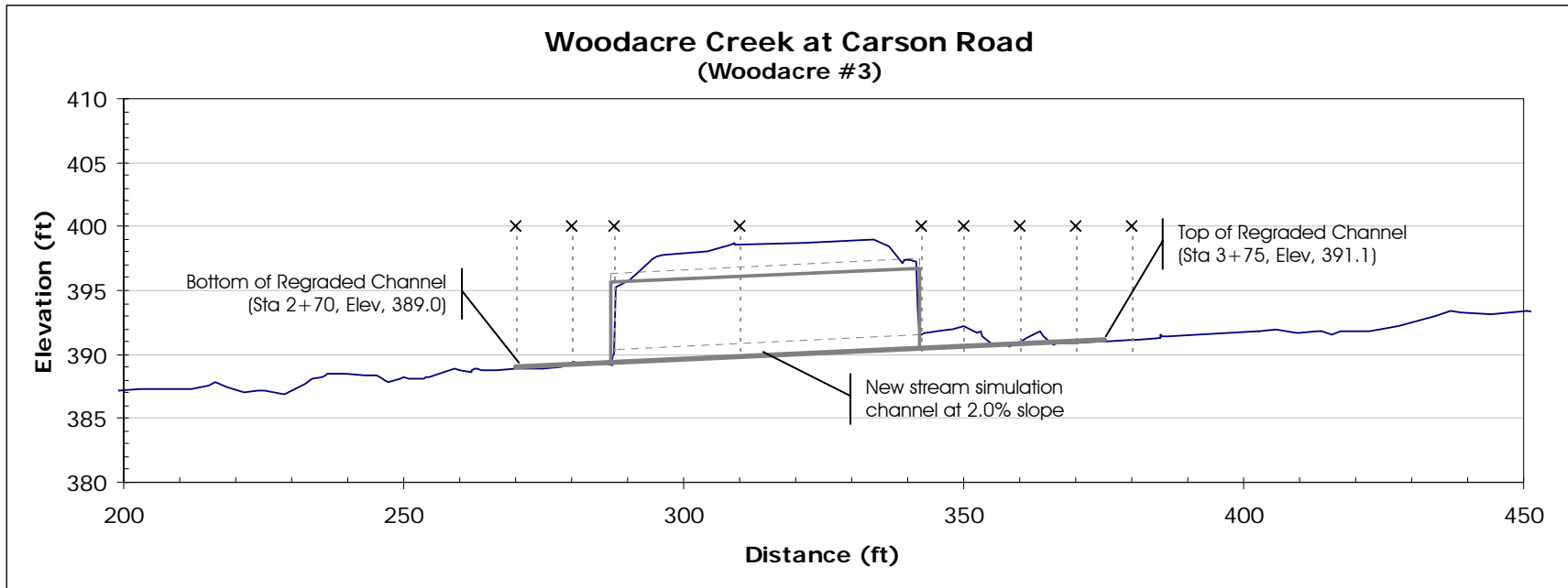
Channel Alignment

Using a 2.0% slope the new stream simulation channel will be 105 feet long, starting at the bedrock outcrop located 20 feet downstream of the culvert outlet (Sta 2+70) and ending approximately 30 feet upstream of the inlet (Sta 3+75) (**Figure 3**).

The upstream portion of the channel will be realigned to create a more direct approach to the culvert, widen the channel and provide a set back from the existing rock wall on the right bank. Currently, the left bank immediately upstream of the culvert consists of deposited fine sediment that narrows the channel, and likely formed as a result of the constriction and backwater created by the existing culverts. The realignment will involve excavation and regrading of this aggraded material along the left bank to match the existing channel width. The entire affected channel length is approximately 30 feet.
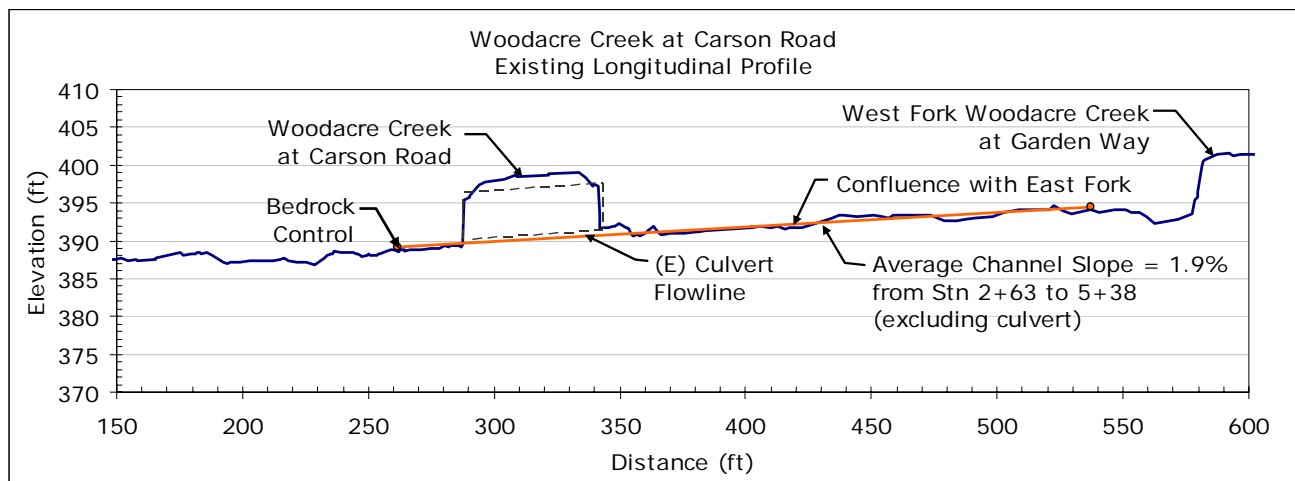
Figure 2. Existing channel profile, along West Fork of Woodacre Creek upstream of the confluence. The average channel gradient for the 275 ft long reach is shown. The channel has a relatively consistent slope of 1.9% throughout this reach. The channel bed is controlled by bedrock at the downstream end of the reach.

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Figure 3. Existing (E) and new (N) channel profile through centerline of the proposed crossing and channel. The channel is to be regarded at a 2% slope for 105 feet. A stream simulation design method was used to determine channel geometry and substrate size. Locations of cross sections used in the design are indicated with an X.

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Streambed Simulation Material

The streambed simulation material is a well-graded mixture of rock and aggregate that forms the bed of the new channel. The mixture is designed to:

(1) Match the material of the adjacent channel in size, composition and mobility,

(2) Form a well compacted low-porosity bed to avoid subsurface flow, and

(3) Provide a channel bed morphology similar to the natural channel (i.e. pool-riffle, plane bed, step-pools, cascades).

Streambed simulation material developed following procedures outlined in the draft USFS Stream Simulation Guidebook (USFS, 2006) and using a streambed particle distribution generated from surface pebble counts conducted by Stetson Engineers.

Stetson Engineers described the size distribution of the surface substrate in three locations using a Wolman Pebble Count. Two locations were upstream of the crossing and one was downstream. The pebble count with the largest D84 (84% of material smaller than the D84) was used to size the stream simulation material.

Particles smaller than the D50 control the porosity of the streambed, while the larger particles influence mobility (streamflow that begins transporting the bed material). However, a surface pebble count fails to accurately characterize the frequency of smaller particles found in the subsurface. Through the process of winnowing, the surface of the streambed contains less of the smaller particles than present in the subsurface, which must be accounted for in design of the streambed simulation material.

For designing the streambed material, the D50 and larger particles were sized to closely match the size and gradation of the substrate measured in the pebble count (rounding to the nearest common size class). Particles smaller than the D50 where sized to provide a low porosity mixture using a modified Fuller Thompson method (USFS, 2006), which is adapted from the aggregate industry (**Figure 4**).

Finally, the mobility of the proposed streambed simulation material in the arch culvert was compared to the mobility of the substrate measured in the pebble count in the natural channel. The analysis found that in both cases D50 and D84 becomes mobile at approximately the same flow, which was close to the 2-year flow of 112 cfs.

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The final gradations (**Table 1**) are used to develop the construction specifications for the streambed simulation material.
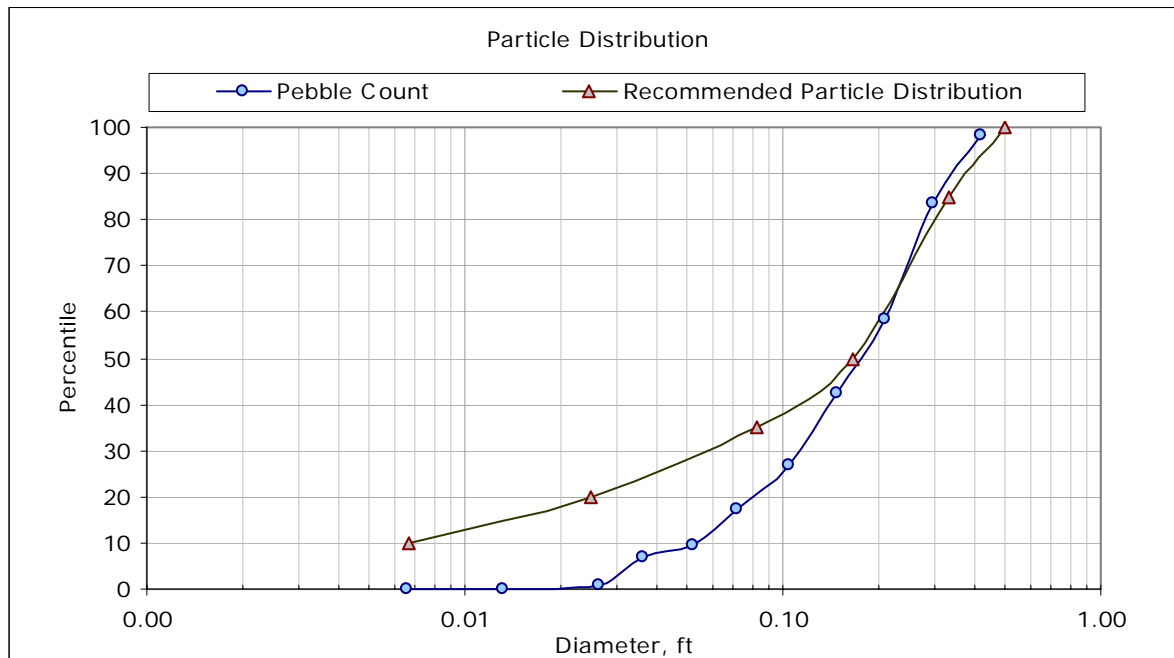
Figure 4 – Particle size distribution for the streambed material measured using a Wolman Pebble Count and the recommended size distribution for the streambed material inside the new culvert.

Table 1 - Final design gradation for *stream simulation material* in the new channel.

| Percent Finer	10	20	35	50	85	95
Particle Size	< 2mm (sands and silts)	0.4 inch	1.0 inch	2.0 inch	4.0 inch	6.0 inch

Channel Shape

Channel Width

Several methods were used to estimate the appropriate active and bankfull channel widths for the stream simulation channel. Channel widths were determined using a combination of field observations, measurements, upstream channel cross sections from the topographic survey, and hydraulic calculations of water surface elevations at various return-period flows. The final design has an active channel base width of 8 feet, and top bankfull width of 12- feet. Therefore, the width between the arch culvert footings should be at least 12 feet.

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Streambed Shape

During winter flow, the channel is expected to adjust the streambed shape, forming a defined thalweg with shallow areas along the sides of the channel. To initiate this process and concentrate low-flows ensuring adequate water depth for adult fish, the channel bottom is designed with a 7.5H:1V side slope towards the center (**Figure 5**).

Stream Banks

Stream banks are constructed of various sized rock at the edges of the active channel. Banks are intended to be rigid and create slower and shallower water along the margins of the channel. The top of the banks are located 2 feet above the toe of the active channel. The width between the top of the banks is equal to the design bankfull width of 12 feet. The channel is designed to contain 1.5-year return flow within the banks. Stream banks will be constructed in the project reach outside of the culvert. Banks adjacent the upstream rock wall can be placed against the exiting rock to provide reinforcement and offset flow. Evaluating the condition of the existing rock wall is beyond the scope this report.
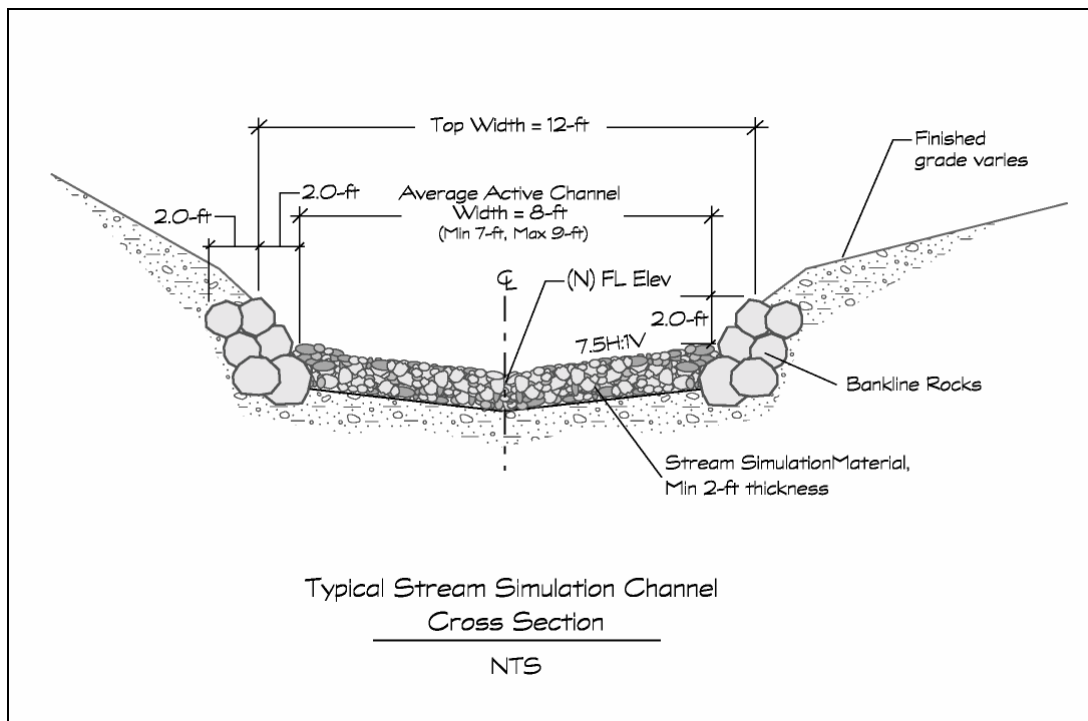
Figure 5. Typical cross section for new channel with streambed simulation material and rock banklines. New channel in the culvert will have rock clusters along concrete footings instead of a continuous bankline.

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Rock Clusters

Due to the elevation and thickness of the concrete footings, including banks inside the culvert was impractical. Instead, an alternative approach is used to keep the thalweg towards the center of the channel and avoid "trenching" along the footings. A series of four rock clusters will be placed along footings; two on each side. Constructed of large rock, they are intended to guide the thalweg to the center and create slower moving water along the edges that smaller fish can swim through.

Rock Structure Size, Shape, and Placement

Rock structures consist of large rocks strategically placed to control the grade of the channel bed. The proposed channel regrade contains two channel spanning rock structures, similar in construction to rock weirs but placed at grade with the finished channel bed. They are located 10 feet and 30 feet upstream of the new culvert inlet. These structures are designed to maintain the upstream channel grade. They are expected to remain at grade with the channel and not create a drop greater than a few inches.

The rock used to construct the rock structures (see plans for location) is not part of the engineered streambed material. Instead, the rock in the structures is intended to be stable up to the structural design flow. For the Carson Road crossing the stable rock size is between 2.0 and 2.5 feet in diameter.

Predicted Hydraulics

Using the channel shape developed in the concept design the water depth and velocities were predicted in the stream simulation channel at the 1.5, 2, and 100-year return period flows. The same analysis was performed using a representative cross section from the upstream channel to compare hydraulic conditions to those in the proposed stream crossing. Results from the hydraulic analysis were also used in the mobility analysis to ensure that the stream simulation bed material would not be more mobile than that bed material in the natural channel.

We used WinXSPro (USFS, 1998) for the hydraulic analysis and assumed uniform flow conditions. Hydraulic roughness (Manning's n) of the channel was estimated using a combination of three flow dependent equations that predict roughness as a function of particle size, water surface slope, and wetted channel geometry (Thorne and Zevenbergen, 1985; Limerinos, 1970; Mussetter, 1989; Jarrett, 1984). Predicted water depth in the new channel and velocities in the stream simulation channel are shown in **Table 3** and **Figures 5** and **6**.
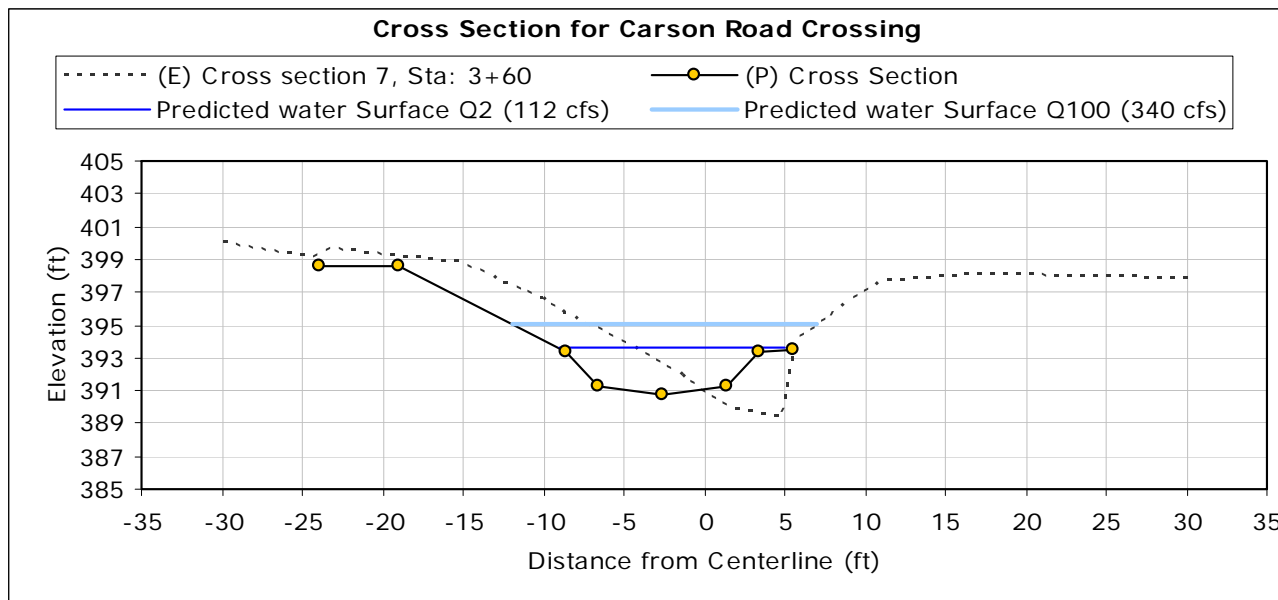
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Table 3 –Hydraulic Conditions in the new channel at the Carson Road crossing on Woodacre Creek estimated 1.5, 2 and 100-year return period flows.

		Predicted Conditions	
Recurrence Interval	Flow (cfs)	Depth (ft)	Velocity (fps)
1.5-year	60	1.6	3.1
2-year	112	2.8	4.2
100-year	340	4.3	6.8

Notes: A D_{84} of 1.0 feet was used in the Thorne and Zevenbergen method to predict Manning's roughness for calculating velocity and depth during the 100-year event.
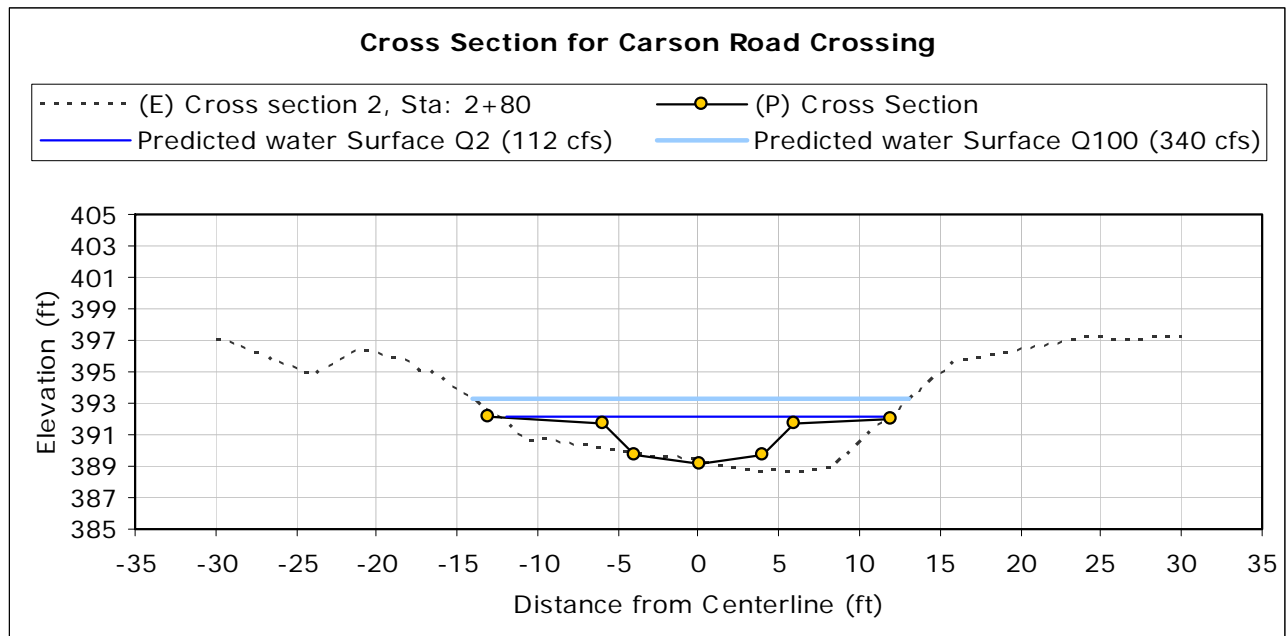
Figure 5. Predicted water surface elevations with the new channel shape at Q_2 (112 cfs) and Q_{100} (340 cfs) at cross section 2+80, located 10 feet downstream of the new crossing.

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Figure 6. Predicted water surface elevations at Q_2 (112 cfs) and Q_{100} (340 cfs) at cross section 3+60, located upstream of the new crossing in the area of the existing rock wall on the right bank.

Preliminary Culvert Recommendations

Based on the channel widths required for the stream simulation design and to provide capacity up to the 100-year flow event of 340-cfs we recommend the following culvert dimensions for an open bottom, multi-plate arch.

- A minimum width between the culvert footings of 12 feet to contain the bankfull channel and rock clusters.
- A minimum rise of 5 feet to maintain a 100-year capacity with debris.

Footing, and wingwall design is beyond the scope of this conceptual design.

Conclusions

To provide fish passage at the Woodacre Creek at Carson Road crossing we propose to replace the existing two culverts with a large span open bottom crossing and construct a natural channel bed designed using the stream simulation method. The new crossing should have a minimum channel bed width of 12-feet and a minimum rise of 5 feet. The new channel would be regraded at a 2% slope for 105 feet and be composed of a streambed material sized to match the adjacent channel. Rock structures would be used

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to maintain the grade upstream of the project reach and rock clusters would be used to direct the thalweg away from the culvert footings.

The project will provide a significant improvement in upstream passage conditions for adult and juvenile coho salmon and steelhead trout and provide ecological connectivity for Woodacre Creek.

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